Mozambique's Future

Modeling Population and Sustainable Development Challenges

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Executive Summary
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Foreword

Science, like government, tends to be compartmentalized into disciplines. A division of labor is useful because it allows for in-depth expertise and efficient action. The only problem is that the real world is not compartmentalized, and changes in population, development, and environment are interwoven. Over a short time horizon these intersectoral dependencies may not be very important, but over a long planning horizon it becomes imperative to address a country's future in a comprehensive interdisciplinary and interministerial manner.

This type of comprehensive analysis of long-term future options has been the explicit goal of this project, which combines more traditional descriptive analysis with interactive computer modeling. The project has been carried out in the context of a population–development–environment (PDE) framework of analysis, developed at IIASA over the past decade and applied to earlier case studies, with close substantive collaboration between IIASA and the national partner institution. Such collaboration between national and international experts, which lies at the heart of the PDE approach, also proved to be a highly successful strategy in this case.

This Executive Summary is only one output from the project. Major scientific books documenting the work in detail will soon be available, along with a CD-ROM and a Web site (www.iiasa.ac.at/Research/POP/pde/) with the full computer model and other important documentation that will allow the user to personally evaluate alternative strategies and scenarios toward the country's sustainable future development.

It is our hope that these findings will be discussed in both academic and political circles at the national and international levels, and that this discussion may lead to closer collaboration among countries in the Southern African region on these vital longer-term challenges.

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Major Findings and Policy Recommendations

The Mozambique population–development–environment (PDE) study was conducted from 1998–2001 to explore the prospects for sustainable development in Mozambique up to 2020. Four major issues were selected:

1. What will be the impact of the HIV/AIDS pandemic in the next decades?
2. How will school enrollment lead to higher skills in the labor force by 2020?
3. Can poverty be erased in the next 20 years?
4. What role will water play in development, in particular, water provision by rain to rural areas, and infrastructure to cities?

To capture future uncertainty, many different scenarios were made with a simulation model developed especially for the project by the report authors and other scientists at the International Institute for Applied Systems Analysis.

Impact of HIV/AIDS on the population

By 2020, HIV/AIDS will reduce the population size by 22%–31% compared to a situation without the epidemic. Without HIV/AIDS, population size is projected to be 27 million in 2020; with the disease, population size will be 18–20 million. HIV/AIDS, together with the effects of education, is likely to halt or even reverse rural population growth by 2020, while the urban population will continue to increase.

Interventions, such as safe sex through condom use and a vaccine, can start to reduce HIV prevalence immediately after the intervention takes effect. For example, with a rise in condom use to 80% by 2010, prevalence would start to decline immediately, from 16% today to 6% in 2020. Unfortunately, these interventions do not halt the progression of AIDS deaths in the next decade, as these are already built into the present HIV prevalence rate.[1] In fact, the full impact on population size and AIDS deaths will only start to be felt a decade after the interventions take place. Because of these lags, it is imperative to begin with policies as early as possible. We found that the best results follow from a three-pronged policy, which consists of: immediate increase in safe sex practices, a full-fledged vaccination campaign, should such a measure become available, and use of all possible measures to increase the life expectancy of those infected with HIV.

Education and adult skills

Primary school enrollment, which has risen rapidly since 1992, will experience a sharp slow-down and will probably stagnate after 2005. This is primarily the combined result of reaching universal school intake by 2001, and fewer school-age children as the HIV/AIDS epidemic lowers births and raises child mortality. On the other hand, enrollment in secondary school and university will continue to rise steeply, increasing 6–15 fold by 2020 in various scenarios testing HIV/AIDS, lower repetition, and higher school retention by age. One major implication for Mozambique is that in the next decade, there will need to be a shift in focus from building more primary schools to building more secondary schools. Because primary school enrollment stagnates, while that of secondary school continues to increase, the availability of medium- to highly educated people to teach primary school will rise in the next two decades.

It is not possible to erase the present low levels of education among adults completely by 2020, because many of the adults who are presently illiterate or have low schooling levels will still be alive in 20 years. However, the proportions of adults over 15 with completed primary school (grade 7), completed secondary, and a university degree albeit starting from very low levels in 1997, will more than double for men, and even quadruple for women. The reason women catch up to men in adult education levels is because the present enrollment differentials are smaller than they were in the past. The higher education will be reflected in the skills and productivity of the labor force.

Poverty and Gross Domestic Product (GDP)

Overall GDP is set to increase with continued foreign investment and improving labor force skills. Our scenarios project GDP growth from under $3 billion in 1997[2] to $8–14 billion in 2020. HIV/AIDS will cause reductions of GDP which are at least commensurate with population loss, but possibly more as the disease scares away foreign and domestic investors. The big poverty issue will be continued rural poverty. Agriculture and predominantly poor farmers cannot benefit from exponential growth through capital investment. The benefits of education do not fully accrue to the rural areas as highly educated people live in or move to the cities. Higher functional literacy is expected to improve the productivity of poor farmers by about 40% in the next 20 years, which would reduce poverty incidence from 90% to about 70%.[3] However, additional attention is needed in the form of appropriately scaled development projects, which include low-input improvements. Although it seems almost inevitable that the income of small farmers falls further behind the urban sector, it should be possible to improve the living conditions for many small farmers.

Water infrastructure for Maputo and Matola cities

From the information that we were able to obtain regarding water supply and demand in Maputo/Matola, it appears that the Pequenos Limbobos reservoir is over-utilized to the extent that the supply cannot be guaranteed even at the 75% level for more than four years. The four major users are households, commerce, industry, and irrigation. Various scenarios, which we implemented that would reduce demand – lower population and industrial growth, and more efficient irrigation technology – did virtually nothing to extend the reservoir lifetime. Since the Pequenos Limbobos reservoir might run dry before new infrastructure is built, we tested alternative water rationing policies. Rationing household demand has almost no effect on an eventual water shortage because it is presently too small in relation to other uses. The most effective policy is to combine water rationing for irrigation when there is a shortage with income compensation for the farmers and an aggressive subsidy to convert farmers to more efficient irrigation methods. This would extend the reservoir lifetime, guaranteed at the 75% level, to 2011.

1 Introduction

Mozambique, one of Africa's greatest agricultural potentials, endowed with a good measure of marine and mineral resources, emerged in 1992 from a long and destructive civil war, one of the poorest nations in the world. At the end of the war, the countryside was riddled with mines, almost one-third of the population was displaced, and half of its schools had been destroyed. A combination of political will, post-war reconstruction, international aid, and sheer human energy led to impressive improvements.

With the return of families and peace, agricultural output – the economic backbone of 81% of the working population – rose rapidly. In 1993, 765,000 tons of cereals were harvested; in 1999, 1,821,000.[4] Real GDP grew 11% annually from 1992–1999 so that income per capita almost doubled from $121 to $230.[5] The country is becoming less dependent on foreign aid.[6] Schools were built at a rate of more than 500 annually, and the number of students in primary schools increased from 1.3 million in 1992 to 2.5 million in 2000.[7] Infant mortality fell from 161 per 100 births during the last five years of the war to 135 from 1992–1997.[8] Two multi-party general elections have been held since the end of the civil war. Another sign of recovery is the large number of national surveys that have been completed since the war.[9] The data conveyed in these surveys is important for planning and the identification of problems.

While these numbers are impressive, it is evident from recent news that Mozambique's travails are not over. In spring 2000, floods in the southern part of the country, which caused half a million people to flee their homes, accentuated the continued vulnerability of the rural people to capricious weather. Also, Mozambique is now on the list of countries with extremely high levels of HIV/AIDS. New estimates from the Ministry of Health put the percentage of adults aged 15–49 with HIV at 16% and rising. And, the levels of poverty and illiteracy remain high. According to the most recent surveys, 78% of the population was living on less than $2 a day[10] and adult illiteracy was 61%.[11]

Amid such a diverse collection of issues and interactions, we ask: **What are the prospects for sustainable development over the next 20 years in Mozambique?** From the above, it looks as if much of the development prospects are determined by such inherently unpredictable events as war, peace, and weather calamities. Although this is true, there are also many changes and patterns which have a long-term stability and which change only slowly over time. For example, socio-demographic changes, such as labor force skills, and population health have a long momentum. These are very important indicators for the economic development potential of a country. Also, although it is impossible to predict a particular year of heavy rains or droughts, there are long time series of weather from which we can calculate the country's vulnerability to single- or multiple-year weather disasters.

To focus our efforts in answering this bold question, we decided to concentrate on four issues, which are discussed in the next section:

1. Can poverty be erased in the next 20 years?
2. How will school enrollment lead to higher skills in the labor force by 2020?
3. What role will water play in development, in particular, water provision by rain to rural areas, and infrastructure to cities?
4. And, most importantly, what will be the impacts of the HIV/AIDS pandemic in the next decades?

Two problems arise with such a wide and long-term view. One is how to organize the field; the second is how to make projections. In answer to the first problem, we take the IIASA population–development–environment (PDE) approach. In answer to the second, we build a multi-sectoral computer model with which to make future scenarios.

The IIASA PDE approach, initiated by demographers, takes the human population as its starting point – the number of people, the age structure, growth rates, and the distribution over socio-demographic aspects such as educational levels, health, and labor force participation rates. People, as units, are at the center. Emanating from people are their activities, such as material production, government and institutional organization, culture, religion, and individual acts. A selection of these activities can be used as indicators of development. Human

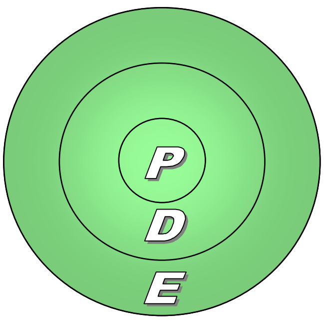

Figure 1. Conceptual organization of the IIASA PDE approach.

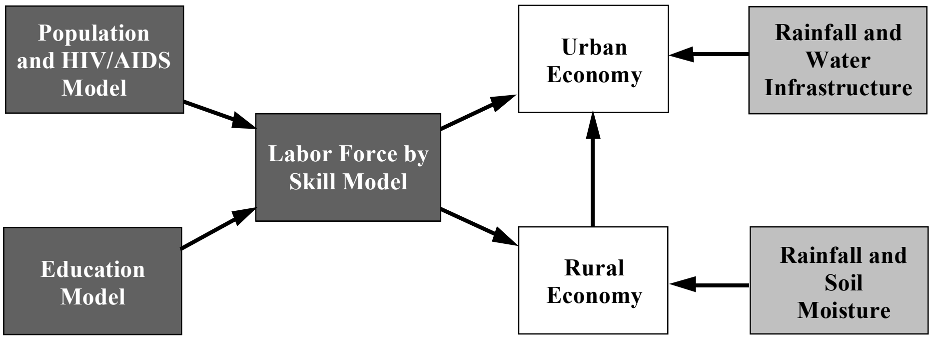

Figure 2. Flow diagram of the basic model structure for Mozambique.

activities take place within an even larger sphere, namely the environment, which encompasses all life-sustaining processes. It provides the material base for everything people do, and is the receptacle of the effects of these activities. Humans are literally embedded in the environment and are also a sub-part of it. Visually, this conceptual organization appears as three concentric circles, with population at the center; then development; and the environment in the outer circle (see Figure 1). This organization differs from that of many other scholars who view population and environment as three separate boxes connected by causal arrows.

Two advantages of the concentric organization are 1) it is more true to reality, and 2) it focuses our analysis on population as a driving force, which deserves to be modeled in its own right.

The PDE model is designed to help policy makers and researchers test various assumptions about the future. It consists of a small number of sub-models, which reflect the three spheres, and which are all interconnected. The models are prepared separately by experts in each area before they are connected. The selection of models follows an in-depth study of the country to identify some of the major interrelationships within and between demographic, social, economic and environmental areas. For the Mozambique study, the models reflect the four focus issues.

These are reflected in the model structure, shown in Figure 2. Each of the sub-models is described in more detail in Section 3. First, we turn to a brief exposition of the four focus areas.

2 Focus Issues of the Mozambique PDE Project

2.1 Poverty and low levels of GDP per capita

There can be no doubt that even today, in spite of high rates of growth in agriculture, industry, and services since 1992, most Mozambicans still live in poverty. According to the 1996 Household Survey data, 78% of the population had less than $2 a day and 38% less than $1 a day.[12] It will require quite a few more years of sustained growth, equally distributed among the population, to erase these high levels of poverty.

The extent of poverty is greatest in the rural areas, where about 90% lived on less than $2 a day in 1996. Even in the cities, a little more than 50% lived in poverty.[13] On average, however, the output per worker was nine times as high in services and industry (mostly located in cities) as it was in agriculture.[14] Most people in the rural areas are family farmers and their dependents[15] who cultivate, on average, about 2 hectare.[16] Only about 20% (by weight) of crops are sold on the market,[17] which is in part due to the small farm size, but also to the poor road and commerce infrastructure throughout the country. Many young men leave the rural areas – as seen by the sex ratios – and go to cities or abroad. Their remittances might raise rural income somewhat, but to a very limited extent.[18]

The farmers are very vulnerable to weather fluctuations. The March 2000 floods are an extreme example, but almost every year, in some part of the country – more in the south than in the north – rains are insufficient, or arrive at the wrong time, causing significant damage to harvest.[19] Clearly, raising incomes is imperative in this situation, both in the rural and in the urban areas.

2.2 Low levels of education and literacy

Economic, as well as political and social, factors have contributed to the building of a society, where the educational shortage is extremely acute. Just before national independence in 1975, more than three-quarters of the adults were illiterate and only 0.5% of the population had completed secondary or more levels of education. Most of the skilled people were lost when almost all

Portuguese left the country at independence. The new government was able to raise school enrollment very quickly, but most educational gains were reversed by the civil war.

Estimations from the 1997 population census indicate that 61% of the adult population is illiterate, and complete primary and secondary education were attained only by 18% and 2% of adults, respectively.[20] Since the peace agreement, the government has again dedicated enormous efforts to rebuilding the school system, and has essentially been able to double its size in eight years. To a certain extent, the shortage of highly-trained people is filled by a large pool of foreigners.[21]

Rebuilding and expanding the school system is not easy. Due to past enrollment deficiencies, there is a shortage of trained teachers at all levels. As a result, the pupil to teacher ratio is very high, which contributes to elevated repetition rates – around 23% in 2000.[22] High repetition adds further strains to the system. The financial means of the government are severely constrained by the many demands of development – parallel to schools, the government needs to expand basic health care, safe water infrastructure, roads, etc. Also, for a variety of reasons, many parents are loathe to send their children to school for long periods: loss of children's labor, school expenses and long walking distances, as well as the perceived futility of education, particularly for girls.

Nevertheless, by 2000, gross enrollment was 91% and the total intake rate[23] was complete, or very near to it. An average girl who started school could expect to complete 4.4 grades and an average boy 4.9, but only 6% would complete the whole 12 grade school cycle. Will these levels of enrollment suffice to reduce illiteracy significantly in the next 20 years, and to raise the proportion of adults with high skills? Will there be enough teachers for continued school expansion? These are some of the questions that scenarios with the model should answer.

2.3 Infrastructure

If output constitutes the muscles of a country, infrastructure is the blood. Transportation and communication are necessary to move food and manufactures from their place of origin to markets. Water and electricity are necessary for modern production. Without access to markets, people have no incentive to produce beyond subsistence, even if they would benefit from sales and the income to buy supplementary goods that they themselves cannot provide. Given Mozambique's soil and climate, it would be easy to produce surplus crops for export or for national urban areas, for example. Without piped water and electricity, it is very difficult to build even simple industries for processing and certainly impossible to have large factories and modern services. As an indication of the shortage of electricity and water, only 3% of the households had electricity, and piped in-house water was limited to only 9% of the households, in urban areas (0.2% in rural areas). These figures indicate a scarcity that would also affect commercial activities.

In Cidade de Maputo there is considerable investment in industry. The water needs for the industry could compete with the needs of households, if the water infrastructure, including pipes, reservoirs, and treatment facilities, are insufficient. To explore these dynamics of competition and limitation, we have done a case study model of the water system for the cities Maputo and Matola.[24]

2.4 HIV/AIDS

A challenge that might override the preceding ones and could undo any progress made, is the HIV/AIDS pandemic that has now also hit Mozambique. The rapid expansion of the virus is one of the most serious challenges to the country's development. The most recent estimates of prevalence indicate that 16% of the adults aged 15–49 are sero-positive.[25] Already in 2000, an estimated 84,000 people died of AIDS.

Mozambique is surrounded by countries with even higher rates of HIV prevalence, such as Botswana, South Africa, and Zimbabwe. In these countries, the epidemic started earlier than in Mozambique, and is already causing reversals in levels of economic growth and life expectancy. Mozambique is closely linked to these countries as a transportation corridor and via labor migration, so the disease could spread easily to the country.

In the past decade, the HIV/AIDS epidemic emerged silently and unexpectedly, due to a failure to interpret and communicate information about the present situation and expectations for the future. It is hoped that the scenarios of this study, with a range of alternative assumptions concerning the increase of prevalence and interventions, will form a base for planning to combat the disease.

3 Model and Scenarios

The structure of the model and scenario discussion in this section follows the concentric circles of PDE. First come the population scenarios, which include the effect of HIV/AIDS. Second, the education and labor force scenarios, combined with variations in population. Third, the economic and environmental components are added to population, education and labor force scenarios.

3.1 The effect of HIV/AIDS and policy interventions on the population

3.1.1 Model description

HIV is an infectious disease, which means there is a relationship between prevalence, incidence, and susceptible population. The most basic dynamic is that the more people are infected, the more the disease spreads to the healthy people, so in turn, the more are infected. How quickly new people are infected depends on the relationship between prevalence and incidence, which is determined by biology and behavior.

If an infected person is healed or dies right away, the prevalence never has a chance to build up and cause an epidemic. On the other hand, if an infected person lives with the infection for a long time, prevalence has the opportunity to increase. This is the case with HIV, where the average time until the outbreak of full-blown AIDS in Africa is estimated to be 7–10 years. Once a person in Africa has AIDS, the annual mortality is very high, at least 50% annually.

Other factors that can limit the spread of the HIV infection are safe sex practices (especially condom use), treatment of other sexually-transmitted diseases, bottle-feeding infants of HIV-positive mothers and other interventions. In the future a cheap vaccine might halt the disease.

Figure 3 shows these basic dynamics and the intervention points to limit HIV and AIDS. We have incorporated the relationship between prevalence and new incidence. If the relationship is higher, then HIV prevalence rises faster. The model also includes the three intervention possibilities in the figure. Further, all the dynamics are incorporated into a multi-state age and sex-specific

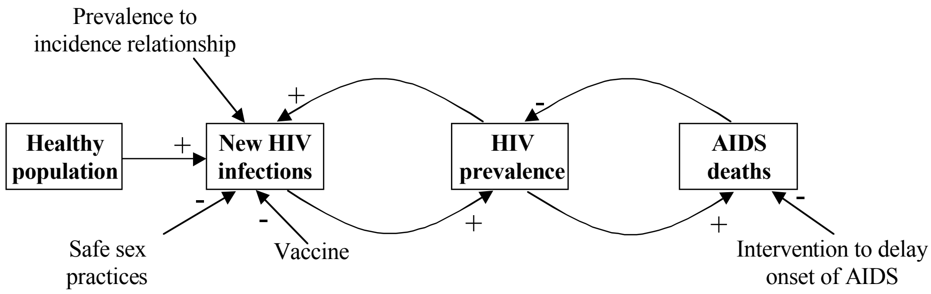

Figure 3. Flow diagram of HIV and AIDS dynamics.

population projection model.[26] With the model, we can make scenarios, which take into account different rates of the diffusion of HIV and the effects of various policies.

3.1.2 Scenarios for HIV/AIDS

The projections for HIV/AIDS calculate population by age and sex, and various indicators such as prevalence and new incidence. For factors other than HIV, namely fertility, non-AIDS mortality, and migration, the assumptions are identical to those used in the population projections of the National Institute of Statistics.[27] There is a slow fertility decline from 5.7 in 1997 to 3.9 in 2020; life expectancy increases from 42 in 1997 to 55 in 2020 (without AIDS).

For our base, or most likely scenario (BaseAIDS), we reproduce the HIV prevalence projections made by the Ministry of Health and the National Institute of Statistics.[28] In these projections, HIV prevalence rises from 16% to 17% and remains constant thereafter. In addition to the base scenario, we present six others, two of which have different assumptions concerning the spread of HIV (a NoAIDS scenario and an AIDSHigh scenario), and four have different assumptions about interventions. The scenarios are:

1. BaseAIDS, where there is but a slight increase in the use of condoms, from 3% among women and 9% among men in 1997[29] to 10% for both sexes by 2020. The prevalence-to-incidence ratio is set to reproduce the 17% constant prevalence projected by the Ministry of Health and the National Institute of Statistics.[30] Assumptions on fertility and mortality are those of the national population projection by the Instituto Nacional de Estatistica. We believe that this scenario is optimistic.
2. NoAIDS, a scenario where the HIV prevalence in 1997 and all preceding years is set to zero. This is used purely for comparative purposes to evaluate the impact of the epidemic.[31]

3. AIDSHigh, where prevalence continues to rise (higher prevalence-to-incidence relationship), following the path of neighboring Botswana and South Africa. This is a pessimistic scenario.
4. AIDSSafeSex, which has the same assumptions about the prevalence-to-incidence relationship as BaseAIDS, but condom use is much higher, namely 40% by 2010 and 80% by 2020. This situation recreates the developments in Uganda, where safe sex has increased rapidly.[32]
5. AIDSVaccine, in which a cheap vaccine is introduced in 2010 and through a rapid campaign, the whole population is vaccinated by 2014 (emulating similar campaigns against smallpox).
6. AIDSLowProgression, which considers a 45% decline in the progression rate from HIV to AIDS, essentially extending the life expectancy of those who are sero-positive, similar to what has happened in developed countries.
7. AIDS3Policies, which combines all three intervention policies.

3.1.3 HIV/AIDS scenario results

The demographic impact of HIV/AIDS will be on the growth rate as well as on the age structure of the population. Like other sub-Saharan countries, Mozambique's growth rate is high, and the present age and sex structure is a wide-based pyramid with many young people and few elderly.

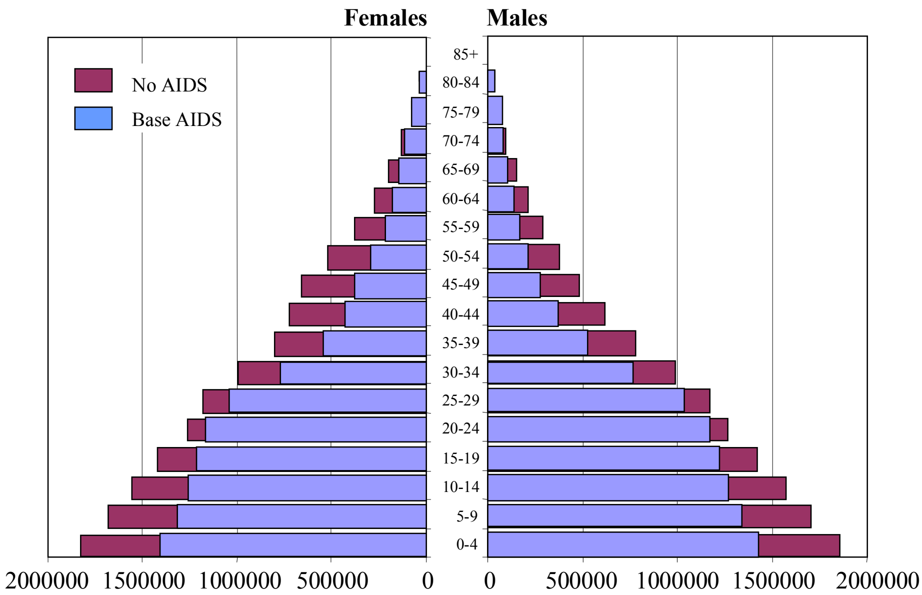

Figure 4. Age and sex structure in 2020 according to the BaseAIDS and the NoAIDS scenarios.

In the context of HIV/AIDS, this well-known pyramid shape will be altered. Fertility reductions will be accelerated because HIV lowers fecundity by about 30%. Also, child mortality will increase. Large portions of young-and middle-aged adults will die of AIDS, causing two large dents (one for each sex) in the pyramid, while the effects in the age group 20–29 are much smaller. Figure 4 shows the population age structure in 2020 as it would have been without HIV/AIDS and as it might be according to the BaseAIDS scenario. One interesting result is that the dependency ratio, ages 0-14/ages15-64, is the same in both scenarios; in other words, there will be the same number of adults caring for children in both scenarios. However, many of the children will be AIDS orphans living, probably, with relatives, although some might not have any close relatives remaining.

In Figure 5 we see the impact of HIV/AIDS on population size. If there were no epidemic, the population would rise to 26.8 million by 2020. That number is 6 million less, namely, 20.8 million with the BaseAIDS scenario; with AIDSHigh, the population in 2020 would only be 18.4 million and declining. The disease would also lower life expectancy by 4–9 years.

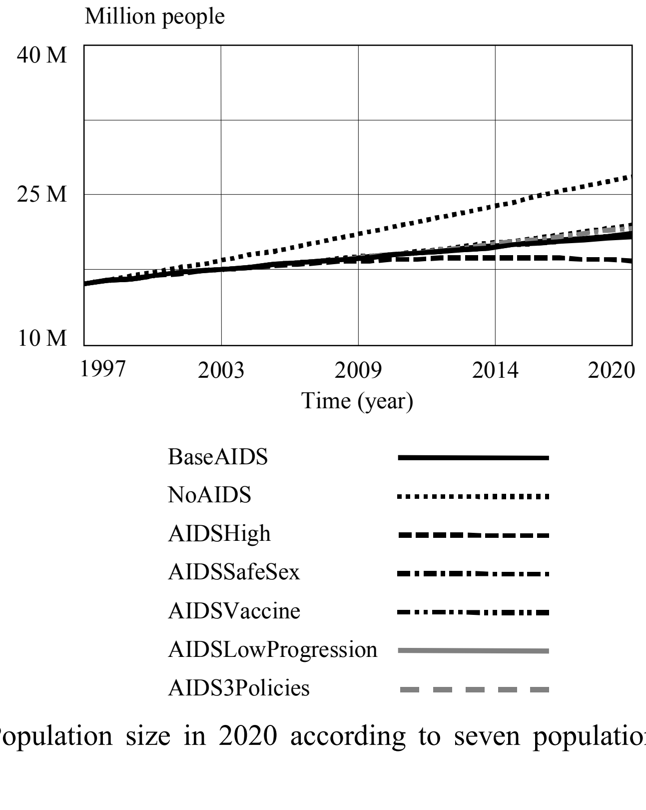

Figure 5. Population size in 2020 according to seven population HIV/AIDS scenarios.

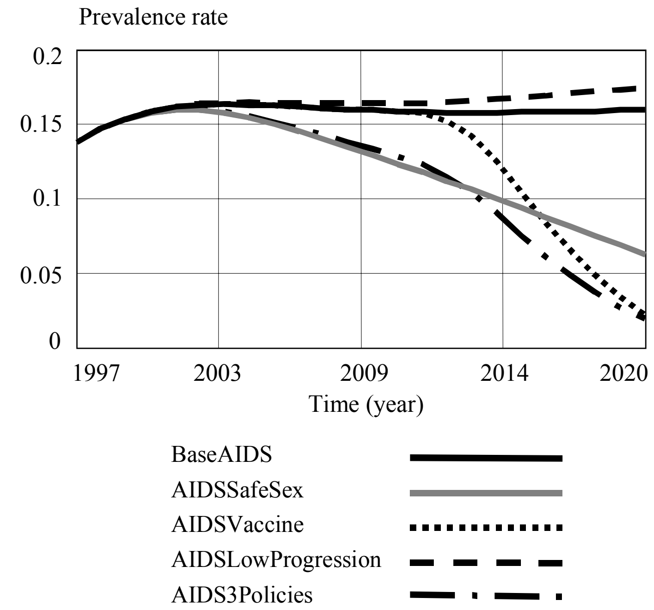

Figure 6. The HIV prevalence rate in 2020 according to the BaseAIDS scenario and four intervention scenarios.

While the three assumptions on the speed of HIV/AIDS diffusion make a large difference to population size, the impact of the various policy interventions is much smaller, so small that they are hardly visible in the figure. The reason for these tiny impacts by 2020 lies in the momentum of HIV/AIDS. Mortality and population size are not affected until 7–10 years after new infections occur. Even in the purely hypothetical situation with no further infections from 2001 onwards, AIDS deaths would still continue to rise for almost another decade before falling. If the vaccine, condom use and low progression interventions are not fully implemented until 2010 or later, the population effect by 2020 will be small. However, if we extend the population projections, say to 2050, a big impact is visible: with the AIDSSafeSex and AIDSVaccine scenarios, the population would be 32.3 and 34.0 million, respectively, compared to only 22.3 million in the BaseAIDS with no interventions.

The first impact of HIV/AIDS interventions is to reduce the HIV prevalence rate, shown in Figure 6. Here, we see large differences by scenario. Higher condom use, starting in 2000, would begin to lower the prevalence rate immediately. Even without any further interventions, prevalence would be only 6.2% in 2020. We assume a vaccine would be implemented much faster than condom use, however, condom use is preferable because it is a policy that can be implemented starting today, whereas the vaccine is uncertain. The intervention that does not reduce prevalence, but in fact raises it slightly, is the AIDSLowProgression. The direct result of prolonging the HIV incubation period is that people with the virus live longer, but that means they are also able to pass the virus on to more people. Still, the lower progression rates are essential for humanitarian reasons, and should be pursued whenever available. A good strategy is to combine all three interventions, shown in the AIDS3Policies scenario. This leads to the lowest prevalence rates by 2020.

The main lesson from these scenarios is that reducing HIV/AIDS requires long-term dedication. The leading indicator for the success of a prevention policy is prevalence rates, which should decline. Later, fewer AIDS deaths will follow. From the Demographic and Health Survey 1997, we know that most people have heard of HIV/AIDS, but most have not changed their sexual behavior. Therefore, we recommend a large and active campaign to promote condom use, particularly among those with many partners.

3.2 Education

3.2.1 Model description

Basically, the present low levels of educational achievement among Mozambican adults are the fruit of a past with low school enrollment rates. In the same way, to project future adult education – the essential ingredient to development – one needs to start by projecting school enrollment, including school intake and drop-out rates.

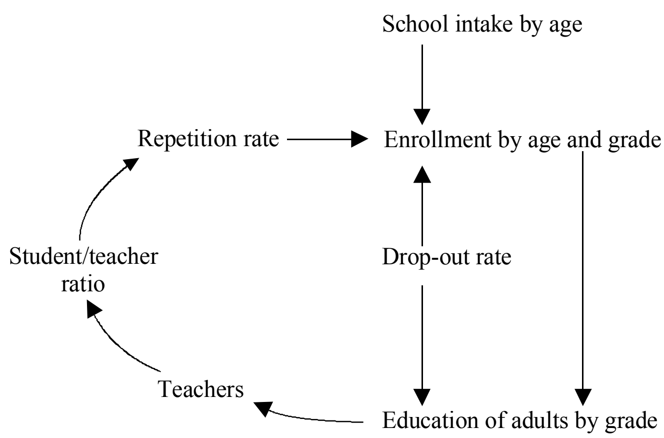

Figure 7. Flow diagram of school enrollment and teacher hiring dynamics captured in the education model.

In Mozambique, school entry occurs at many ages, starting at age 5, and ranging up to young adulthood. Most people who enter school do so between the ages of 5 and 12. Similarly, school departure occurs throughout the school cycle. In each grade between 6% and 47% of the students leave (the higher drop-out rates occur at transitions from one school level to the next). Most, but not all, people who leave school are teenagers. This rather complex situation is captured in a model with school enrollment by single-year age groups and single grades from 1–12, as well as separate university enrollment (see Figure 7).

A particular concern for the country is whether or not there will be enough teachers, particularly at the lower primary school level. This concern is more acute in the face of the HIV/AIDS epidemic. Teachers are expected to have completed the teacher training program, but in many cases, the shortage of teachers leads to hiring people who have simply completed a certain minimum of general education.[33] The number of teachers is important because teachers are needed to fill new classrooms; also, the student/teacher ratio is a measure of school quality. A cross-sectional analysis of African countries in 1995 shows that where the student/teacher ratio is lower, the repetition rate is as well.[34] Repetition, which averages 23% in Mozambique, influences enrollment and greatly increases the inefficiency of school. This dynamic is also in the model and shown in Figure 7.

3.2.2 Scenarios for education

The scenarios for education calculate school enrollment and the education of adults, which is an essential part of the economic development scenarios discussed in Section 3.3.3. They also calculate the number of teachers, the student/teacher ratio and the repetition rate as measures of school quality. Furthermore, different levels of HIV/AIDS are included in all the scenarios. Five scenarios are discussed:

1. EducBase, in which total school intake stabilizes at 100% by 2001, and the drop-out rates remain constant from 1997 on, as they appear to have done from 1997 to 2000. Teachers for lower primary school are hired from the total pool of those people who left school with grade 8 or higher. The hiring rate is set to reach a goal of under 30 students per teacher by 2020, down from 62 in 1999. The repetition rate is sensitive to the student/teacher ratio: when there are more teachers, the repetition rate is lower. It falls from 0.23 with a student/teacher ratio of 62 to 0.09 when the ratio is 30. The population assumptions are identical to those in BaseAIDS.
2. EducHigh, which explores the possibility of lowering drop-out rates over the next 20 years in school and in the university. Once near complete school intake has been achieved, it is logical to concentrate efforts on

reducing the loss of students throughout their school lifetime. Also, as the economy continues to expand, improvements in the school system might be easier to finance.

3. EducConstantRepetition, with inflexible repetition rates, regardless of the student/teacher ratio, is calculated to measure the extent to which repetition contributes to inefficiency.
4. EducBaseNoAIDS, which is calculated to see what would have happened without the epidemic.
5. EducBaseAIDSHigh, which is calculated to test how sensitive the education system is to a possible worse outcome of the epidemic.

3.2.3 Results of the education scenarios

In 2000, there were 2.6 million pupils in primary and secondary schools. According to the EducBase scenarios, the total number of pupils at all levels will increase over the next 20 years, as it has in the past eight years since the peace agreement. By 2020, with EducBase, there will be 4.1 million students. While this is a substantial increase, it reflects much lower annual enrollment growth rates than occurred from 1997–2000. HIV/AIDS is a large factor causing slower growth of school enrollment. Besides a rise in numbers, there will be a change in the *composition* of students by grade. Whereas in 2000, 88% of all students were enrolled in lower primary school (grades 1–5), by 2020, EducBase projects this proportion to be 74%. The proportion of students in secondary school rises from 3% in 2000 to 11% in 2020. The shift is apparent in all scenarios.

The rise in the number of primary school pupils will slow down markedly around 2005 (shown for the five scenarios in Figure 8) because of constant intake rates. The intake rate recently grew quickly, but is presently about universal and is projected to remain constant, so the only increases in first-time grade 1 enrollment will come from population growth. With quasi-constant intake, the fast rise in the number of lower primary school pupils from the past eight years continues only for another five years or so, until grades 1–5 are "filled up". At that point, enrollment will reflect the population size, universal intake rate, prevailing repetition and school retention rates.

Without HIV/AIDS (EducBaseNoAIDS), primary school enrollment would continue to rise beyond 2005, albeit at a much slower pace than recently, to 3.6 million instead of the 2.9 million projected in the EducBase scenario. In other words, by 2020, 700,000 students are lost to the primary schools because of HIV/AIDS, some of them because of early deaths, some of them because HIV lowers fertility. With EducBaseAIDSHigh the population in primary school would actually begin to shrink.

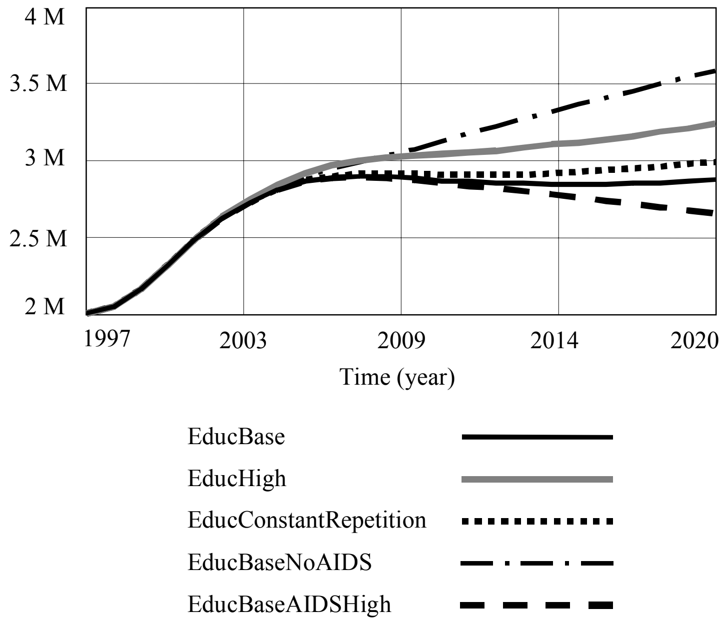

Figure 8. Students enrolled in primary school (grades 1–7) in five education scenarios, from 1997–2020.

Another factor, namely lower repetition rates, has the effect of lowering primary school enrollment, although not nearly as much as HIV/AIDS (compare EducConstantRepetition with EducBase). With repetition constant at 0.23, primary enrollment reaches 3.0 million students in 2020, which is 100,000 more than in the EducBase, where repetition falls to 0.09 by 2020. Of course, fewer pupils due to lower repetition is a good thing, whereas losses due to HIV/AIDS are not.

Some compensation of the student losses could come from lower drop-out rates. In the EducHigh scenario, primary enrollment is about half-way between the EducBase scenario and EducBaseNoAIDS.

Table 1 shows the five scenario results for the number of students at primary, secondary, and tertiary levels in 2020. In all five scenarios, the student population is bigger in 2020 than in 1997. However, secondary and tertiary students, while fewer than primary in absolute terms, grow more in relative terms. In the three scenarios with EducBase and HIV/AIDS variations (EducBase, EducBaseNoAIDS, EducBaseAIDSHigh), students increase from 51,000 to over 300,000 in secondary, and from under 7,000 to about 50,000 in tertiary.

Table 1. Total number of students in primary school, secondary school, and university in 1997 and in 2020 according to five scenarios.

	Primary school	Secondary school	University
1997[35]	2.0 million	51,285	6,528
2020			
EducBase	2.9 million	343,488	49,317
EducHigh	3.2 million	774,668	104,133
EducConstantRepetition	3.0 million	242,672	31,579
EducBaseNoAIDS	3.6 million	397,615	51,461
EducBaseAIDSHigh	2.7 million	334,495	49,005

What we see here is the ripple effect of school intake expansion. When school intake rises, it is first evident in grade 1, and gradually continues up the grades. Once school intake stabilizes, first the primary grades "fill up" for another 5–7 years. Next, secondary school grades begin to fill up. This takes longer, more than 20 years, due in part to the effect of repetition rates. Lastly, tertiary education benefits and continues to expand long after secondary school has stabilized. In industrialized countries, for example, tertiary enrollment is still growing.[36]

Lower drop-out rates (EducHigh) have a particularly large effect on secondary and tertiary education. Enrollment at these levels would be twice as high compared with EducBase in 2020. The increase would be 15 fold at both higher levels, reflecting an average annual growth rate of 14% from 1997–2000 (this growth is actually slower than what we observed from 1995–2000).

Repetition, which we assume is primarily the result of the student/teacher ratio, plays an interesting role in the composition of the student population. Presently, the average repetition rate is 0.23. If repetition rates were to remain constant (EducConstantRepetition), there would be more primary school students, and far fewer secondary and university students. In part, this is due to the way the model is formulated. In our model, school drop out is a function of age, which means each scenario gives students a range of years in school before they drop out, rather than a certain range of grades they finish. When repetition is higher, fewer children flow through to higher grades, meaning more remain in primary school and fewer go to the higher levels. In relative terms, continued high repetition would cost the country one-third of its secondary school pupils compared to the EducBase scenario.

All scenarios indicate that in the next decade, there will need to be a shift in focus from building more primary schools to the building of more secondary schools. However, there is large uncertainty regarding the number of future secondary students (ranging from 243,000 to 775,000 in 2020).

Table 2. Student/teacher ratios and the repetition rate in lower primary school, in 1997 and in 2020 according to five education scenarios.

	Student/teacher ratio	Repetition rate
1997	61	0.23
2020		
EducBase	29	0.09
EducHigh	29	0.09
EducConstantRepetition	36	0.23
EducBaseNoAIDS	32	0.10
EducBaseAIDSHigh	29	0.09

Clearly, it would be desirable to improve the two indicators regarding school quality, namely repetition rates and the student/teacher ratio, but a real concern is whether there will be enough qualified teachers, particularly with future AIDS deaths. To reach a goal of 30 teachers per pupil, the annual increase in the number of teachers continues through 2020, although the annual increase rate declines from about 3,000 per year to just over 1,000 teachers. The model does not explicitly formulate teacher training because at present, many teachers are hired without official qualifications, but with a certain minimum level of general education. We therefore assume the pool of potential teachers is simply those who leave school at grade 8 or higher. The scenario variable is "proportion of those who leave school who are hired as teachers." In 1997, we assume it was 1.5%.[37] In EducBase, by 2020 we assume it would be lower, namely 0.7%. This is sufficient to reach a student/teacher ratio of 29. This is possible because 1) the number of primary students stabilizes, while 2) the number of people with higher grades continues to increase throughout the projection period.

Surprisingly, AIDS assumptions and lower drop-out rates have almost no impact on repetition and the student/teacher ratio, as shown in Table 2. HIV/AIDS reduces the number of births, and hence, pupils, at the same rate as it reduces teachers. The model does not include the disruptive effects of AIDS, such as a higher turnover of teachers or an overall loss of population, so there might be other negative effects that are not included here. The lower drop-out rates (EducHigh) do not affect these numbers either. Lower drop-out rates would raise the number of primary school pupils, but at the same time also the number of people leaving school at higher grades.

In brief, school enrollment in Mozambique will continue to increase in the next two decades, with particularly strong growth in the higher levels. Efforts to reduce drop-out rates and repetition will bear fruit in the form of raising secondary and university enrollment – as much as doubling or trebling it.

HIV/AIDS will result in fewer teachers, but also fewer students, and the net effect on the student/teacher ratio is small, if there are not other disruptive factors arising from the epidemic. Next, we look at how school enrollment translates into the skills of the labor force.

3.2.4 Impact of education and HIV/AIDS on the labor force

Education does two things to the labor force: it increases the skill level and therewith the productivity of workers, and it moves people to cities (because the more educated a person is, the more likely he or she lives in an urban area). Meanwhile, AIDS takes people out of the labor force, through death and through home-nursing of AIDS patients. Our model calculates these effects for the urban and rural labor force. Moreover, we include an independent, non-education related urban migration force, so that over time, even within each educational level, larger proportions live in cities (1% per year in the unskilled and medium-skilled categories in the EducBase scenario). The labor force scenario results follow directly from the education scenarios above, with the addition of the non-education related migration component.

The combined forces of rising education, non-education related rural–urban migration, and HIV/AIDS have an enormous impact on the labor force. First, let us discuss education. Table 3 shows the educational level of adults aged 15 and above according to two of the education scenarios above, namely EducBase and EducHigh. HIV/AIDS does not impact the proportional distribution of education among adults, at least, not with the dynamics that are covered by the model.

Table 3. Educational achievement of adults in percent of those aged 15 and above, according to two education scenarios.

	No schooling	Grades 1–6	Complete upper primary (grade 7)	Compete upper secondary (grade 12)	University degree (both sexes combined)
Males					
1997[38]	42	51	6	1.0	0.12
2020 EducBase	29	56	13	1.9	0.40
2020 EducHigh	29	51	15	5.0	0.97
Females					
1997	61	37	2	0.3	
2020 EducBase	46	45	8	0.7	
2020 EducHigh	46	40	10	3.3	

The table shows that although educational levels rise, there will still be a sizeable proportion of adults with no or very little education by 2020 because of built-in lags in the age structure (many people with no education today will still be alive 20 years from now). On the other hand, the proportion of adults with complete primary, complete secondary, or with university degrees, while low in 1997 and in 2020, will increase multi-fold. In particular, women experience large gains. The proportion of women with complete primary education rises from 2% in 1997 to 8%–10% in 2020 (depending on the scenario). The increase in secondary education is even larger: women with complete secondary school rise from 0.3% to 0.7%–3.3%. Women catch up to men in both levels of education because school enrollment is more equal today than it has been in the past.

These shifts in education impact the urban and rural labor force to the benefit of the urban areas. In addition, HIV/AIDS and non-education related migration are important. Figure 9 shows the urban (panel A) and rural (panel B) labor force following from the three above-mentioned education scenarios, EducBase, EducHigh, and EducBaseNoAIDS, along with a fourth scenario which disregards non-education related migration, EducLowMigration, which is otherwise identical to EducBase.

If there were no HIV/AIDS (a purely hypothetical comparison), the rural labor force would continue to grow, despite increases in education and migration. As it is, with the EducBase scenario there is stagnation, part of which is due to migration, as a comparison with EducLowMigration shows; another part is due to AIDS (compare to EducBaseNoAIDS). Without HIV/AIDS, the rural labor force in our scenario is 6.8 million in 2020; with AIDS, it is 5.4 million, a 21% loss.[39] If there were any improvements in school retention (EducHigh), the rural labor force would actually start to decline significantly. The reversal of growth in a sub-Saharan rural population is highly unexpected. Yet, a similar model also finds it for Botswana and Namibia. The possible economic impacts are discussed in Section 3.3.3. Meanwhile, the urban labor force is expected to continue to grow, albeit more slowly due to HIV/AIDS.

While the absolute size of the labor force says something, a true reflection of the economic potential of workers includes skill level as well as size. To capture this economic potential, we calculate the *effective labor force* separately from the absolute labor force size. The effective labor force incorporates relative productivity weights given to each skill level.[40] In particular, the productivity weights make a big difference in the *effective* urban labor force (Figure 9, panel C). In all four scenarios, the *effective* urban labor force rises steeply, despite HIV/AIDS. The high education assumptions are even sufficient to offset population losses from HIV/AIDS (compare EducHigh with EducBaseNoAIDS). This should not lull us into complacency with regard to HIV/AIDS, since the higher educational levels could also take place without the

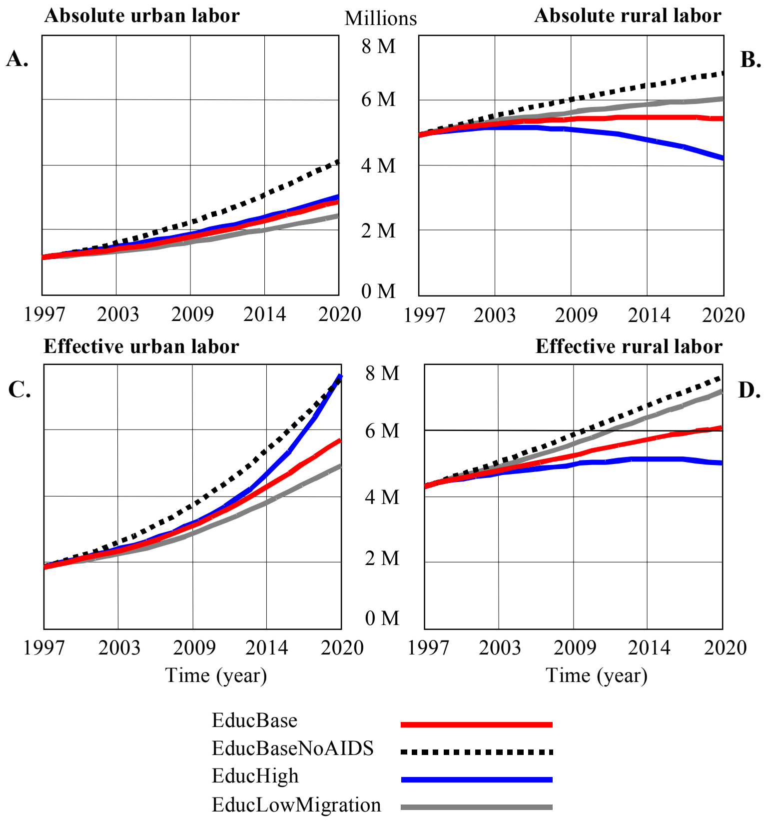

Figure 9. Urban and rural labor force according to four scenarios.

epidemic, and in fact, are probably more likely to do so. Due to productivity the *effective* rural labor force (Figure 9, panel D) could continue to rise in the next 20 years despite HIV/AIDS and rural–urban migration, but much more slowly than the urban. Although the rural areas benefit from education, they do so less than the cities.

3.3 Economic development and environment

3.3.1 Economic and water model description

In this section, we move rapidly outwards on the concentric circles (recall Figure 1), to include economic development and the environment. Out of many environmental factors, we have selected water – rainfall and soil moisture – to model. Figure 10 shows a flow diagram of the economic and water model. Economic production is divided into urban and rural sectors (equivalent to

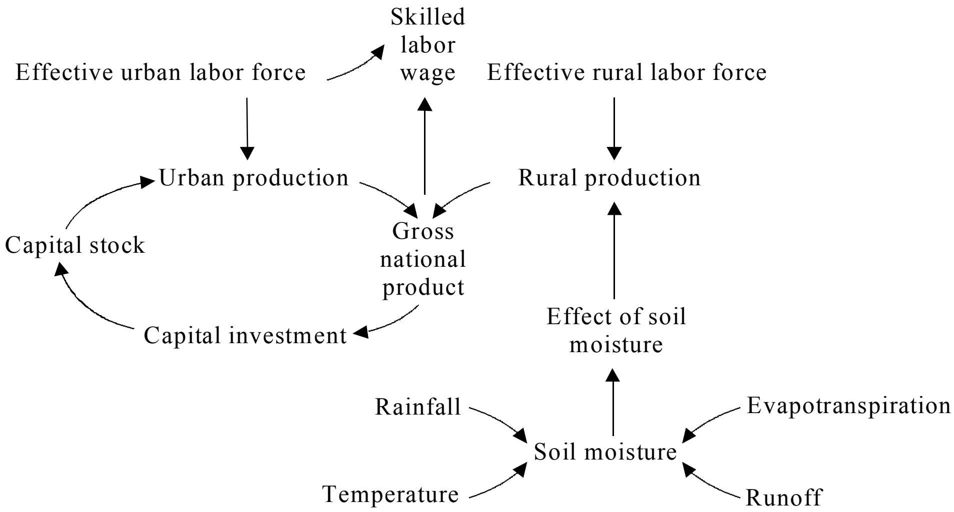

Figure 10. Simplified flow diagram of economic and environmental dynamics captured in the economic and water model.

industry and services versus agriculture). Urban production is defined by a Cobb-Douglas function,[41] which includes effective urban labor, capital stock, and productivity. Changes in the capital stock are determined by the rate of domestic investment as a proportion of GDP. We also calculate the wage for highly skilled labor.[42] Agricultural production is essentially a function of effective rural labor, productivity, and the effect of soil moisture and rainfall.

The water model uses a simple but physically-based hydrologic approach to calculate soil moisture.[43] The model includes 25 national and international rainfall catchment areas, which supply water for the major international rivers running through Mozambique. Not all water is available for extraction or crop growth. Most of it is lost through evapotranspiration and run-off. The model calculates the complex non-linear dynamics of these processes, including rainfall, temperature, vapor pressure, latitude, and soil moisture capacity. Unfortunately, it was not possible to find data, which would allow us to model in detail the effects of the timing and quantity of rainfall on agricultural output. The connection of rain and harvest is therefore very simple: a curve specifying the relative reduction of harvest as a function of rain shortfall in March.

3.3.2 Economic development and climate scenarios

Different economic scenarios emerge directly from the HIV/AIDS and education variations discussed above, as both labor force size and skills are affected. In this section, we discuss three of them:

1. EconBase, which incorporates the assumptions from EducBase.
2. EconNoAIDS, with the same assumptions as EducBaseNoAIDS.
3. EconEducHigh, with the same assumptions as EducHigh.

The economic assumptions in these three scenarios are that labor productivity changes only through higher education levels and that the domestic investment rate is 20% of GDP from 2000–2020. The model is calibrated to historical data from 1997–1999.[44]

In an additional scenario, EconProductive, productivity gains in both economic sectors are *added* on top of those related to education. Higher urban productivity can come from, for example, modernization of capital, a shift to higher value-added activities, better bureaucratic organization, or upgrading of energy, water, and transportation infrastructure. In the rural sector, the conventional recipe for productivity gains includes hybrid high yield crop varieties, large-scale irrigation, fertilizer and pesticide use, monoculture, and mechanization. In recent years, there has been a growing recognition that the output of poor, small farmers can be much better improved with simpler methods, such as mulching, natural pest control, draft animals, small water catchment and irrigation constructions, contour farming, and the like. In our scenarios, we assume a doubling of output per worker, which is 50% more than in the EconBase scenario, as the result of an active campaign to reach all farmers. This reflects a realistic (even somewhat low) value found in field studies working with the above low-input improvements.

In a fifth scenario, EconClimateChange, we consider the impact of climate change on especially rural production. Global Circulation Models[45] predict an average rainfall increase of 12% for Mozambique and a rise in temperature of 1.5 degrees by 2020.

Finally, EconLowInvestment calculates production with a low, 10% of GDP investment in urban capital per year from 2000 on. This could be one of the impacts of HIV/AIDS as foreign investors are scared away by the epidemic.

3.3.3 Results of the economic development and climate scenarios

All of the scenarios lead to higher income levels by 2020, as shown in Table 4. The EconNoAIDS scenario would allow us to reach an average real GDP growth rate of 6.6% per year. With HIV/AIDS in the EconBase scenario, the growth rate is only 5.7%. Per capita income in 2020 would be $511 (1995 dollars, not corrected for purchasing power parity) in the EconBase scenario. It is actually just slightly higher than without HIV/AIDS, because one of the factors of production, namely capital, is not reduced by the epidemic. However, these gains do not take into account the probable disruptive effects of the epidemic that could lower GDP and income per capita more than in our scenario.

Table 4. Urban and rural output (in millions of 1995 dollars), national and rural output per capita (in 1995 dollars) in 1997 and in 2020 according to six scenarios.

	Urban output	Rural output	GDP per capita	Rural output per capita
1997	1,757	909	165	79
2020				
EconBase	9,244	1,411	511	111
EconNoAIDS	11,578	1,769	497	111
EconEducHigh	11,299	1,164	601	117
EconProductive	11,786	1,924	658	151
EconClimateChange	9,278	1,433	514	113
EconLowInvestment	6,928	1,411	400	111

In all six scenarios, urban production is much higher in 2020 than it was in 1997 (1.757 billion 1995 dollars). By 2020 in the EconBase scenario, it would be more than 9 billion, and with some education or production gains, it would be in excess of 11 billion. Even low investment leads to almost 7 billion in urban output. If the lower investment were an indirect result of HIV/AIDS, then by 2020 the disease would have cut GDP by 40% compared to the situation without HIV/AIDS. These large, across the board gains in spite of HIV/AIDS are a result of the effective urban labor force. Also, capital levels in the 1990s were so low, that even modest investments make a big difference.

Urban production increases, but not as quickly as the supply of skilled labor (secondary schooling complete and university degree). As a result, although skilled labor is very scarce in absolute terms, it becomes *relatively* less scarce, and wages will tend to decline over the next 20 years (see Figure 11). This phenomenon, where skilled labor rises more quickly than the economy, is a typical situation following a rapid increase in school enrollment.

In contrast to urban production, rural production gains are much smaller, partly because there is no exponential growth engine of capital investment. In fact, an analysis of Table 4 shows rural vulnerability and highlights some of the challenges of raising rural incomes.

The rural income per capita,[46] already much lower than urban incomes in 1997, falls behind even further in all the scenarios. In 1997, rural income per capita was estimated at $79 (1995 dollars) compared to $165 for the country overall. In the EconBase and EconNoAIDS scenarios, rural per capita income would increase by 40% to $111, largely due to more people with medium skills (grades 4–11 completed). This gain falls far short of the $500 national income per capita in the same scenarios.

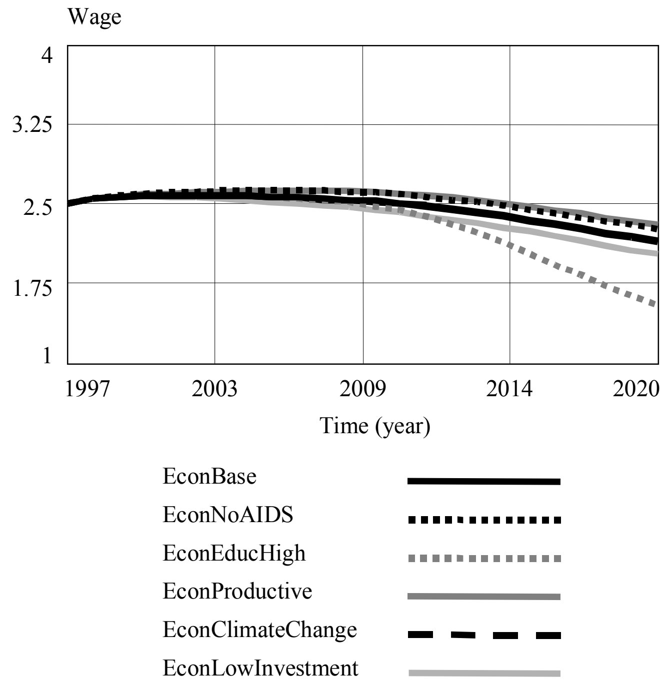

Figure 11. Wage rate for skilled labor in six economic development scenarios.

Productivity gains from EconEducHigh have only a small impact on the rural population's income, basically because the scenario increases mostly the highly skilled labor force (recall Table 3), and people in that group of workers almost all move to the cities. As a result, the EconEducHigh scenario leads to a 20% overall per capita income increase (a big return for investment in schools!), but only 7% in the rural areas.

The only intervention that has an appreciable effect on rural income per capita, is productivity increases, which we assume are through low-input measures appropriate for small farmers. With the resulting doubling of rural income per capita, the rural poverty incidence (less than $2 a day per capita in purchasing power parity) would decline from 90% to about 50, if the income gains were spread in proportion to present income distribution.[47]

The rural areas are particularly vulnerable to climate change, however, this might be one factor which shifts in their favor. The 12% rainfall reduction basically removes the threat of serious droughts by 2012 as shown in Figure 12. Basically, the relative soil moisture will be above 1 all years thereafter. The flipside is that floods will become more frequent. Unfortunately, the data did not allow us to model the effect of excessive, or excessively concentrated

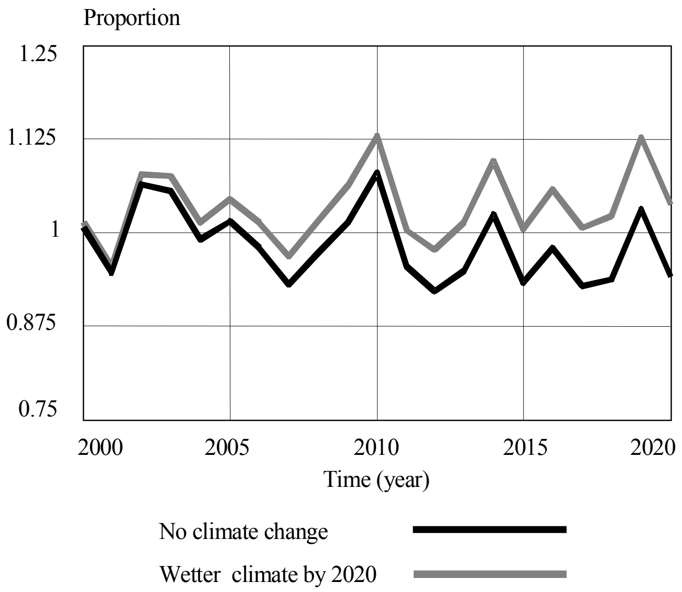

Figure 12. National relative soil moisture in two climate scenarios. Droughts occur when the relative soil moisture falls below 1.

rainfall on harvest, so the net effect on agriculture in terms of average production and annual variability, is unknown.

3.4 Case study: Water balance of greater Maputo City

There is no doubt that the water supply of greater Maputo City,[48] or Maputo/Matola as we shall refer to it below, can absorb only a limited amount of water demand growth before an expansion of the system needs to take place. In this sense, Maputo/Matola is not any different from most other cities, including those in industrial countries. However, the growth of demands could be very rapid in the next few years, as more industry and people locate in the Maputo/Matola area. The strains on the system and the competition between different demands are a typical example of the interaction of population and development with infrastructure and the environment.

The present supply of Maputo/Matola is the Pequenos Limbobos dam, which is fed by the Umbeluzi river. It is not expected to provide enough water even for another decade. Plans are underway to bring water from the Incomati river or to abstract groundwater. How much water will be needed is uncertain; it depends on the future immigration rate, industrial growth, proportion of households with an in-house water tap, and the efficiency of the urban irrigation system, to name a few important variables. It also depends on weather, a highly uncertain variable in Maputo. In wet years Pequenos Limbobos might supply ample water, but not if there is a two- or three-year drought series. It is impossible to predict when droughts will occur; we can only say something about the general pattern with which they come. To test these uncertainties we made the Maputo case study model. It models the Pequenos Limbobos reservoir, including the effects of rainfall and temperature fluctuations, with which we can make variable series of future weather. It also includes four types of demands: household, commercial, industrial, and irrigation, each of which can be varied at will.

Presently, only 29% of the population in Maputo/Matola have water in their homes; 21% take water from public taps. Half of the people in the cities do not have any piped water, but use wells. Clearly, in the next few decades, one of the imperatives is to improve this supply. The growth in household water demand comes from three trends: population growth, more people connected to pipes, and consumption increases for those who are connected to pipes.

Industrial water demands are low, as industrial development has only really picked up in the past couple of years. In 2000, the 1.9 billion dollar aluminum smelter, Mozal, went into operation just outside Maputo. It will require a lot of water. But incremental growth of many smaller industries will lead to rising industrial water demand as well.

By far the biggest user of the water from Pequenos Limbobos and the Umbeluzi river that feeds it, is irrigated agriculture. Water demand is unequally distributed throughout the year, dependent on the growing cycle of crops. On average, 11–15,000 m^3 per hectare is used every year, which means that irrigation technology is rather inefficient. In 1997, we estimated water for growing crops at 75% of the total demand in the Maputo/Matola area. In most developing countries the majority of water use is for irrigation. Agriculture provides essential food and income and irrigation water is much cheaper to provide than household water because it is generally untreated.

The scenarios reflect different growth paths and policies in the three sectors: households, industry, and irrigation. In particular, the scenarios focus on three issues. 1) For how many years will the Pequenos Limbobos supply be reliable, given alternative growth assumptions? In other words, how many years does Maputo/Matola have to build an infrastructure that taps another supply source? 2) In the case of a temporary depletion of the Pequenos Limbobos reservoir, what are the best policies? If it turns out that due to an unfortunate series of dry years, for example, the Pequenos Limbobos reservoir drops below a critical level, the city will be forced to take water rationing measures. 3) A lot depends on the rainfall patterns, which are uncertain, particularly when we include climate change, and we explicitly include this uncertainty. Seven scenarios are discussed in this section:

1. MaputoBase. In this scenario, the population of Maputo/Matola grows 4% annually.[49] The proportion of people with in-house or in-yard connections rises from 0.29 to 0.82 in 2025,[50] and their per capita consumption of water rises as well. General industrial and commercial demand rise 6% per annum. Moreover, industrial demand is augmented by a few large projects, such as Mozal, the new aluminum smelter. Irrigation remains constant, as does the climate.
2. BaseClimateChange. This is the same as MaputoBase, except that average rainfall is 12% higher by 2020, the medium assumption in the Global Circulation Models.
3. LowPopIndustry. An active decentralization policy is immediately implemented to locate growth foci in other cities, such as Beira. Population growth is only 2% per annum and industry 3%.
4. 3Policy. In addition to lower population and industrial growth, the government pursues an active program to increase irrigation efficiency to 7,000 m^3 per hectare annually by 2010. The technology and implementation of this policy among farmers would be funded, for example, by foreign grants.
5. PopRation. This is the same as the MaputoBase scenario, except that when the Pequenos Limbobos reservoir drops to acutely low levels, water is rationed among households, so that those who have an in-house or in-yard connection can use only 0.6 m^3 per person per day, instead of 3.4 m^3 as in 1997.
6. IrrigationRation. Instead of households, farms are rationed when Pequenos Limbobos is dangerously low. All irrigation water is cut off when the reservoir has less than 100 million m^3 (the depletion level is 63 million m^3).
7. EfficientIrrigationRation. This is the same as above, but combined with an aggressive policy to subsidize and implement efficient irrigation technology.

Table 5 shows the water demands for Maputo/Matola from four sectors in 1997 and in 2020 according to three scenarios. In 1997, irrigation is by far the largest user of water, but in the two coming decades, that will change. Household demand overtakes irrigation as it increases in absolute terms more than any other demand, from under 3 million m^3 of water per month to over 15 million m^3 by 2020. With a smaller population of 2.4 million in the LowPopIndustry scenario, instead of 3.3, household demand would be less than 11 million m^3 per month. Industrial demand has the largest relative growth from 0.44 to 6.17 million m^3 per month in the MaputoBase scenario. It would rise to less than 3 million m^3 per month in the two policy scenarios. Average monthly irrigation demand falls to 4.4 million m^3 per month in the 3Policies scenario.

Table 5. Maputo/Matola water demand in 1997 and in 2020 according to three scenarios.

Million m^3 per month, including losses	1997	MaputoBase 2020	LowPopIndustry 2020	3Policies 2020
Household demand	2.67	15.26	**10.95**	**10.95**
Industrial demand	0.44	6.17	**2.79**	**2.79**
Commercial demand	0.38	0.92	0.92	0.92
Irrigation demand	8.52	8.52	8.52	**4.40**

To get an idea of the dynamics in the Pequenos Limbobos reservoir as a result of the annual weather fluctuations, seasonal irrigation demands, and long-term demand trends, Figure 13 shows the supply in the MaputoBase and BaseClimateChange scenarios. The selected 23-year weather pattern has neither an upward nor a downward trend in rainfall from 1997–2020.[51]

The figure shows the seasonal fluctuations within the year caused by the rainfall and irrigation demand fluctuations.[52] There are also larger fluctuations, which are caused by total annual rainfall variance and demand trends. A dry year in 2002 in this simulation can totally deplete the reservoir. When the reservoir reaches 63 million m^3 it is functionally empty, as shown by the flat section of the scenario lines along the bottom of the figure. The BaseClimateChange scenario, which gradually brings more rain, gives little respite.

According to this simulation, the reservoir will be depleted in 2002 regardless of climate change. Of course, the weather pattern is not likely to be exactly the one included in this simulation. To see the effect of possible extreme weather time series, we show the MaputoBase scenario with a dry 23 years and with a wet 23 years (it should be noted that the weather series are taken directly from actual historical time series as recorded from 1900–1995). The two extreme weather series are shown together with the original MaputoBase in Figure 14. With the MaputoBaseDrySeries, the reservoir runs dry in 2001; with the WetSeries, not until 2015. It is impossible to tell which weather series will take place, but planners must take reasonable precautions with regard to expecting the worst.

One way to take reasonable precaution is a calculation which gives the cumulative probability that the reservoir will run dry, given a collection of possible weather patterns. This is shown in Figure 15 for six scenarios.[53] We ran a series of 19 simulations for each scenario.[54] For each year x we calculated the proportion of years in which the reservoir was first depleted, before and including year x. The figure shows that even at present levels of use, there is a

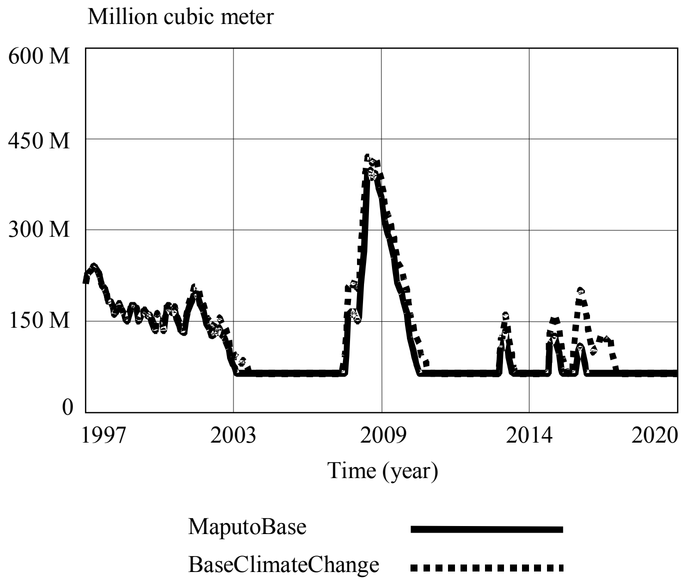

Figure 13. Pequenos Limbobos water supply according to two scenarios and a randomly selected 23-year weather series.

low possibility that the reservoir could run dry, if there were an unlucky series of droughts. In the discussion of the scenarios below, we say that a reasonable precaution with regard to reservoir reliability is when the cumulative probability that the reservoir will run dry is less than 25%.

We found that, with the MaputoBase scenario, there is actually a 25% probability that the reservoir will run dry sometime within the next four years. The probability is 50% within the next eight years, and 90% within 12 years. The LowPopIndustry scenario, with its assumptions about lower population growth and industrial growth, does little to change this. The reason is because even at present levels of water usage – without including future growth in demand – the system is over-utilized to the point where a given drought or series of dry years will cause the reservoir to run dry. One implication is that lower population growth due to HIV/AIDS will not save the city's water system.

The 3Policy scenario envisions a reduction of water use, with aggressive promotion and implementation of efficient irrigation technology. Eventually, population and industrial growth will make up for lower water use, but perhaps the policy offers some years of respite in which the city can build other water supply structures. In fact, even this simulation gives almost no improvement – largely because we assume farmers gradually convert to the new irrigation

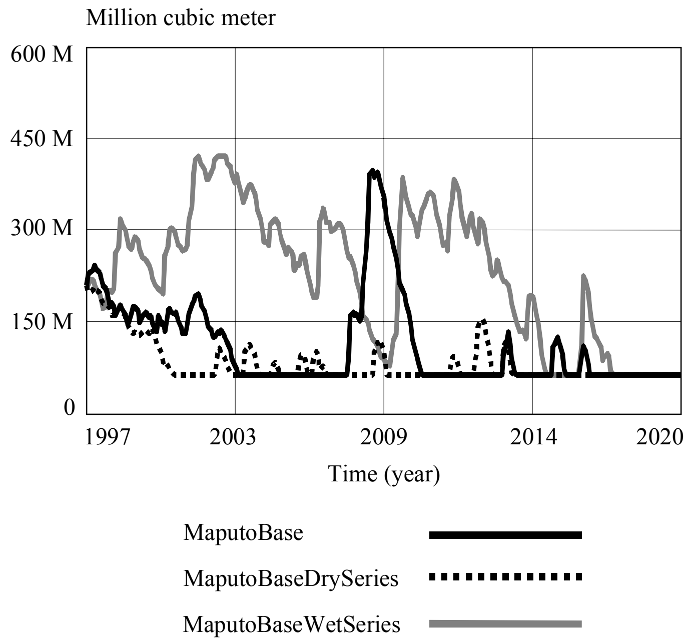

Figure 14. Pequenos Limbobos water supply according to three weather patterns, all with the base scenario for demand.

methods over 10 years, during which time the population and industrial growth immediately use up any surplus that might arise.

It appears then, that all three of the possibilities that we explore to extend the lifetime of the reservoir – climate change, lower household and industry use, and lower irrigation water use – still result in the same 25% probability that the reservoir will run dry in the next four years. That is very little time to build extra water infrastructure.

Given this situation, it seems imperative to explore the policy options, should an acute water shortage arise. Unpopular as such measures might be, some water use needs to be rationed if there is a water shortage. We have implemented two rationing policies. In one, the household water supply is rationed – for example, by having running water only a few hours a day – when the Pequenos Limbobos reservoir reaches 100 million m^3. In the second, water supply for irrigation is cut off completely when the reservoir is that low.

With regard to the household rationing policy (PopRation), it has very little effect on the probability with which the reservoir runs dry, particularly in the next five years. The reason is because now and for the next five years, household water demand makes up only a small portion of the total, so that rationing hardly reduces overall water demand.

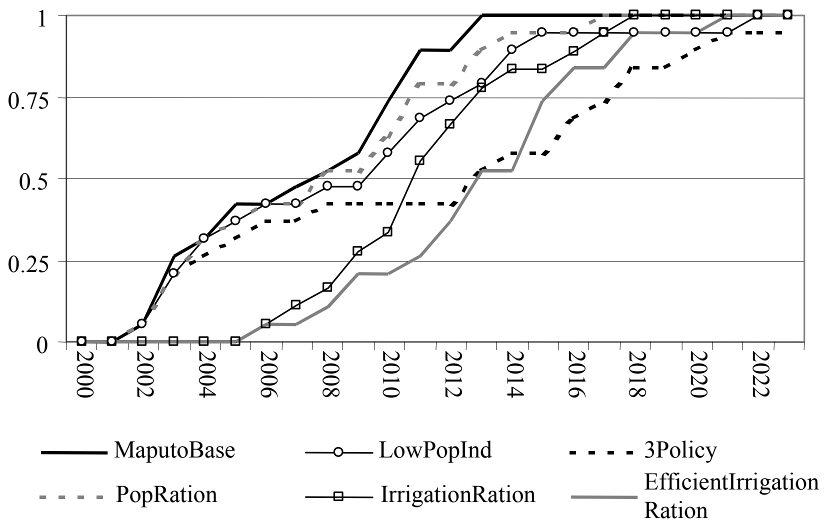

Figure 15. Cumulative probability that Pequenos Limbobos reservoir will be depleted for the first time, by year *x* between 2000–2022, for six scenarios.

The one policy that does work is to cut off water for irrigation during times of shortage (IrrigationRation). In some years, this could mean a partial or complete loss of irrigation water during the critical months of November–January. With an irrigation rationing policy, the 25% probability that the reservoir will be depleted is not reached until 2009. Combined with an efficient irrigation program, the reservoir lifetime could be extended to 2011.

Of course it is a fallacy to say that there are no water shortages in these scenarios, just because the reservoir is not depleted. In fact, there *are* shortages – but they are controlled with rationing to affect only a designated group of users. In the IrrigationRation scenario, the probability that there would be no water in November, December, or January is 25% up to 2010. In fact, 34% of the years up to 2010 are affected though the loss of at least one month. One could imagine that an income compensation scheme for the farmers to reduce the pain of this policy would be a necessity. Combining the irrigation rationing with subsidies to implement efficient irrigation technology can also mitigate the impact of rationing on farmers (EfficientIrrigationRation). In the scenario which combines these two policies, only 14% of the critical months are lost and 19% of the years are affected.

Notes

[1] At present, HIV/AIDS is still a terminal disease. Today, at best, interventions can hope to extend the life of those who are sero-positive.

[2] All figures in 1995 dollars.

[3] Poverty incidence is the proportion living on less than $2 a day in purchasing power parity. Calculations were made based on the *Inquérito Nacional aos Agregados Familiares Sobre Condições de Vida 1996–1997* (1998) Instituto Nacional de Estatística, Maputo. Conversion factors to purchasing power parity obtained from the World Development Report 2000/2001 (World Bank, 2000, Washington, D.C.).

[4] FAO (2000) www.fao.org, statistical database on agriculture. Cereals include maize, rice, millet, sorghum, and wheat. The output of cereals in 2000 was estimated at 1,476,000 tons, a decline from 1999 due to the floods in March of 2000.

[5] World Bank, http://www.worldbank.org/data/countrydata/countrydata.html, and World Development Indicators 1999 (CD-Rom), GDP at factor cost in US dollars.

[6] In 1993, official development assistance was equal to 61% of GDP; in 1999 it was 28%, according to World Bank data above.

[7] 1992 data from UNESCO database www.unesco.org ; 2000 data generously provided by Ilídio Buduia, Head of the Statistical Department, and Virgílio Juvane, Head of the Planning Department at the Ministry of Education, Maputo.

[8] *Anuário Estatístico 1997* (1997) Mozambique (Instituto Nacional de Estatística); Gaspar, M. & Cossa, H.A. (1998) *Inquérito Demográfico e de Saúde, Moçambique* (Instituto Nacional de Estatística).

[9] Among the most important are: 1996 Household Survey by the National Institute of Statistics; 1996 Agricultural Survey, by the Ministry of Agriculture and Fishing; 1997 General Population Census by the National Institute of Statistics; 1997 Demographic and Health Survey by the National Institute of Statistics; 2000 Agricultural Census by the National Institute of Statistics.

[10] World Bank calculations based on the 1996 Household Survey. Numbers in 1993 prices and adjusted for purchasing power parity.

[11] 1997 General Population Census, CD-Rom, National Institute of Statistics, Maputo, Mozambique.

[12] Adjusted for purchasing power parity. Calculations published in the World Development Report 2000/1 by the World Bank (2000).

[13] Authors' estimations based on the Household Survey 1996, using the prevailing exchange rate, adjusting for overall purchasing power parity, and assuming the same household size for all income classes in rural areas, and in urban areas separately.

[14] The value added per worker in agriculture was US$ 235 per year, compared to $2049 in industry and services.

[15] 95% of the rural workers were in agriculture or fishing according to the 1997 population census, and 90% of the farms are small family farms (personal communication, 1998, Dr. Domingos F.R. Diogo, Head of Department of Statistics, Ministry of Agriculture and Fisheries).

[16] Agricultural Survey 1996.

[17] Agricultural Survey 1996.

[18] The FAO estimates that non-farm income was about 15% (*The State of Food and Agriculture 1998*, Rome, FAO, 1998), not a portion of which can be from remittances. According to the Household Survey 1996, the average household income was $51 per month (not adjusted for purchasing power parity), which means that non-farm income averaged less than $13 per month.

[19] Based on a search of international news articles from 1975–2000 which reported floods, droughts and harvest reductions in Mozambique.

[20] 1997 General Population Census CD-Rom, Instituto Nacional de Estatística, Maputo. Mozambique's school system consists of four levels: lower primary (grades 1–5), upper primary (grades 6–7), lower secondary (grades 8–10), and upper secondary. The numbers refer to lower plus upper primary together, and to lower and upper secondary together.

[21] According to the 1997 Population Census, 9.3% of the skilled labor force with complete secondary education or more was foreign.

[22] 2000 data generously provided by Ilídio Buduia, Head of the Statistical Department, and Virgílio Juvane, Head of the Planning Department at the Ministry of Education, Maputo.

[23] Instituto Nacional de Estatística. (1999). Projecções Anuais da População Total, 1997–2020. *Série Estudos N º1*. Intake rate is the proportion of children who can expect to start school given present age-specific levels of intake.

[24] Maputo is the capital city, and Matola is a neighboring city in Maputo Province. The two cities form a contiguous urban area and derive water from the same source.

[25] The prevalence is lower than in neighboring countries, which could be due to the prohibition of commercial sex during the socialist regime and restricted population movement during the civil war.

[26] The original version of this model was developed for Botswana by Warren Sanderson at the International Institute for Applied Systems Analysis, Laxenburg, Austria.

[27] Instituto Nacional de Estatística. (1999). Projecções Anuais da População Total, 1997–2020. *Série Estudos N º1*. Our numbers are slightly different due to a different model structure.

[28] Ministério da Saúde, Instituto Nacional de Estatística e all. (2000). Impacto Demográfico do HIV-Sida em Moçambique.

[29] Numbers found in Instituto Nacional de Estatística (1998) *Demographic and Health Survey* 1997, Maputo.

[30] Ministério da Saúde, Instituto Nacional de Estatística e all. (2000). Impacto Demográfico do HIV-Sida em Moçambique.

[31] This scenario reproduces the most recent population projections made by the Instituto Nacional de Estatística (1999) *Projecções Anuais da População Total 1997–2020 Moçambique Série Estudos N º1*, Maputo.

[32] In 1995 the reported condom use in most recent sexual encounters in Uganda was 58% in urban areas and 16% in rural areas, according to the *Uganda Epidemiological Factsheet on HIV/AIDS and sexually transmitted diseases update 2000*, available at http://www.unaids.org/hivaidsinfo/statistics/june00/fact_sheets/index.html.

[33] According to data from the Ministry of Education, there were only 366 graduates from the training schools for lower primary education in 1998. This is far less than the increase of lower primary school teachers, from 30,513 in 1998 to 33,363 in 1999 (Instituto Nacional de Estatística, 2000, *Moçambique em Números 1999,* Maputo). In addition, teachers need to be hired to replace those who leave or die. We estimate that in 1998, about 6,000 new teachers were hired at the lower primary school level, far fewer than the qualified graduates.

[34] Using the database on the UNESCO website: www.unesco.org.

[35] These numbers diverge somewhat from the actual historical numbers because of estimation procedures in the model.

[36] See, for example, UNESCO website: www.unesco.org.

[37] This number was necessary to obtain 6,000 new lower primary school teachers, enough to replace the estimated 3,000 who retired or died and 3,000 additional teachers.

[38] The 1997 values are estimated based on the available information from the 1997 General Population Census CD-Rom, Instituto Nacional de Estatística, Maputo.

[39] The FAO also estimates that the rural areas will lose about 20% of their population compared to a situation without HIV/AIDS by 2020. However, since they do not account for the effect of education, the FAO might not predict an actual decline of rural population size. See FAO website special page about HIV/AIDS (http://www.fao.org).

[40] The weights were estimated based on a comparison of incomes in different groups. They reflect the income distribution of the 1996 Household Survey. We assume income is ranked by skill – in other words, the unskilled have a lower income than the medium skilled, who have a lower income than the highly skilled.

[41] A standard economic formulation, which is discussed in most textbooks on macro-economics.

[42] The original skilled labor wage model was developed by P. Kibuuka ("The projected supply and demand for professional and technical workforce in Botswana and the impact of AIDS 1991–2020," unpublished manuscript, 1997. Paper available from the author at paulk@dbsa.org).

[43] Hellmuth, M., K.M. Strzepek, and D.N.Yates (2000) Methodological Framework of the Southern African Integrated (SAINT) Model of Water Supply and Demand. Draft available from the author at hellmuth@iiasa.ac.at.

[44] World Bank, http://www.worldbank.org/data/countrydata/countrydata.html, and World Development Indicators 1999 (CD-Rom), GDP at factor cost in US dollars.

[45] Hulme, M., Ed. (1996) Climate Change and Southern Africa: An exploration of some potential impacts and implications in the S.A.D.C. region. Norwich, U.K.: East Anglia University, 104 pp.

[46] Rural income per capita is equal to agricultural output/number of rural workers/1997 ratio of rural population to rural labor force.

[47] Another doubling of productivity would reduce the below $2/day poverty incidence to about 20% of the rural population, assuming the distribution of income gains reflects recent income distribution.

[48] Includes the area of Maputo City, Matola City in Maputo province, and some surrounding rural areas.

[49] The annual population growth of the two cities together averaged 6.3% from 1980–1997 according to the 1980 and 1997 population census data.

[50] As planned or suggested in the Provincial Towns Water Sector Survey. Part C. Town report 13 – Maputo by DHV Consultants, 1992.

[51] Because we are aware that there might be multi-year weather cycles, we decided to use historical series of weather in our scenarios. The 23-year scenario series are selected from 95 years of temperature and rainfall data. Source: Links dataset, from New, M., M. Hulme, and P. Jones (1999) Representing twentieth-century space-time climate variability. Part I: Development of a 1961–90 mean monthly terrestrial climatology. *Journal of Climate* 12(3):829–856.

[52] Most irrigation occurs in the months November, December, January, and coincides with the rainy season.

[53] The low population scenario is left out because the results are visually indistinguishable from those of the base scenario.

[54] To obtain the cumulative probability that Pequenos Limbobos will run dry, we ran each of the four scenarios with 19 different weather series. We then found the first year of reservoir depletion for each weather series. To obtain the cumulative probability that the reservoir would be depleted by year *x*, we summed the number of series in which the reservoir had been first depleted previous to and including year *x*, and divided by the number of series. We are aware that the number of simulations is too small for proper statistical analysis, but it was not feasible to do more with the model. However, they do give an indication of the direction of a proper statistical analysis.